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Innovative Flow Drilling on Magnesium Wrought Alloy AZ31

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Abstract

This article investigates the research of the new application of flow drilling, a chipless hole-making process, on magnesium wrought alloy AZ31 for expanding the lightweight potential of magnesium. The feasibility of the innovative flow drilling on thin magnesium profiles is investigated. Thrust forces and torque during flow drilling are analyzed. Specimens with two different thicknesses have been studied for flow drilling process. Process temperatures during the process are determined by using a thermal imaging camera. The generation of a joint through tapping and thread forming has been examined.

Keywords: Drilling; Magnesium; Alloy; Tapping; Lightweight

1. Introduction

Lightweight components are designed to increase the energy efficiency of vehicle construction. Magnesium is one of the most important lightweight materials due to its low density, and its uses are not fully developed yet **[1]**. Extruded magnesium profiles with complex shapes are widely used in aerospace, nuclear, automotive, and other engineering applications. The thin-walled structures can be assembled by detachable joints to realize a specific function in the lightweight construction.

The manufacturing process of flow drilling, in combination with threading, makes it possible to assemble thin walled lightweight structures **[2]**. In this article, the feasibility of a new application of flow drilling on magnesium wrought alloy AZ31 is investigated for widening the scope of using this material for flow drilling process.

In the beginning, the standard flow drilling process is discussed. It is a forming process, which produces holes in thin walled workpieces without generating chips. The aim of this method is to increase local thickness of the work piece for threading, so that available clamp load can also be increased. In combination with a subsequent thread production, the flow drilling provides the opportunity to generate a detachable connection in the form of an internal thread on a thin walled workpiece or multi-chamber hollow profiles [2].

Fig. 1 illustrates typical stages of flow drilling on a ductile sheet metal specimen. In this process, a rotating conical tool is made to penetrate a thin walled specimen leading to the generating of friction heat which reduces the tensile strength, and as a result plastic deformation takes place. After the tool penetrates the metal sheet, there is no material in front of the tool tip (Fig. 1, III). During flow drilling, back-extruded workpiece material is generated and it is flattened by the tool shoulder upon reaching the drill depth, so that a plain area for screw connection can be produced. An opened bush is formed in the feed direction in a single step without any chip. An internal thread can be machined in this bush. The ultimate thickness of the hole generated in the flow drilling is greater than the thin walled workpiece thickness [2]. Directly manufacturing of joints is an economical and time efficient process, compared to conventional tapping. A joint can be directly manufactured without the use of nuts or threaded bushing.

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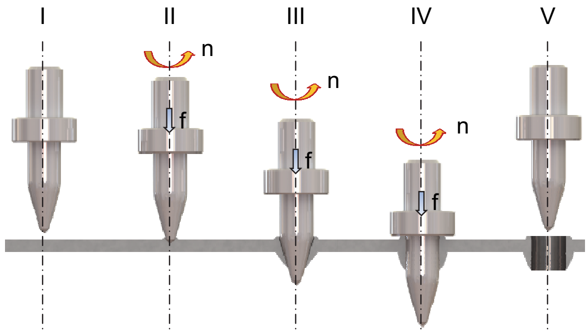


Fig. 1: Flow drilling, standard application [2]

Previous studies dealt with flow drilling on the conventional application of this manufacturing technique, in which an opened bush is formed. The latest research shows that a closed flow-drilled hole can be machined in thin-walled profile, with the same tools used in conventional applications **[3]**. **Fig. 2** represents the process sequence and workpieces connected by using joints made through this new application of flow drilling. The thin-walled workpiece to be machined is clamped on the vice vertically with the thin wall facing the tool. A rotating tool is fed into the work piece with a constant feed rate. In this process, the friction between the tool and the workpiece generates frictional heat and it softens the material.

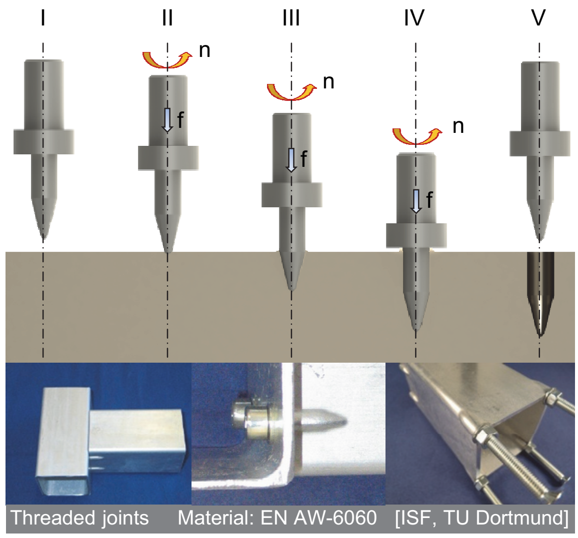


Fig. 2: Flow drilling, new application [3]

Compared to the conventional application of flow drilling, there is always some material in contact with the tool tip (Fig. 2, II - IV). For forming a blind hole, this material must be displaced by the tool in radial direction. The flat profile is expanded locally. Finally, the tool retracts and leaves a hole, whose depth exceeds the local thickness significantly. After the flow drilling process, an internal thread can be machined by thread forming into the blind hole, whose size and depth are greater than the local thickness significantly as well. The work piece can be joined with screws.

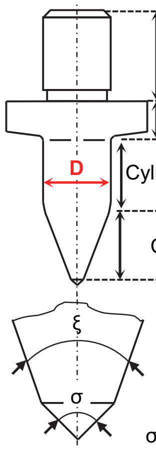
This new method for generating a joint with flow drilling is useful for machining of thin walled flat profiles or multi-chamber hollow profiles, by which its end or stiffening ribs can be used directly [3]. Entirely new opportunity is created for the assembly. During flow drilling, no chips are generated, which is more beneficial for magnesium machining as the magnesium chips may present fire risks **[4]**.

2. Experimental setup, conditions and procedure

To get basic knowledge about the flow drilling of magnesium alloy wrought AZ31, experimental investigations were carried out and are listed below:

- Determining the mechanical loads in flow drilling,
- measurements of temperatures by drilling and followed threading and
- examination of threaded profile.

Two Flowdrill® tools with the diameter $D_1 = 5$ mm and $D_2 = 5.4$ mm were used for this investigation. **Fig. 3** shows the geometry of these tools. The tool material is tungsten carbide in cobalt matrix. For tapping M6 ISO metric, a hole diameter of $D_1 = 5$ mm and for the thread forming a diameter of $D_2 = 5.4$ mm are required **[5]**.



Tool geometry	Tool Nr.1 D_1= 5.0 mm	Tool Nr.2 D_2= 5.4 mm
Shank region	13 mm	14 mm
Shoulder	4 mm	5 mm
Cylindrical region	9 mm	9 mm
Conical region	6 mm	7 mm
Center region	0.75 mm	0.75 mm
ξ: Conical angle	34 °	34 °
σ: Center angle	90 °	90 °

Fig. 3: Tool geometry

Thrust and torque are the main factors in flow drilling. For the determination of mechanical loads in this process, a GROB BZ 40 CS machining center was used. A schematic overview of the experimental setup is shown in **Fig. 4**. The specimen was held in a hydraulic vice. A Kistler piezoelectric drilling dynamometer model Typ 9125A, which is the tool holder at the same time, was used to measure the axial thrust forces and torque during flow drilling. **Table 1** presents the parameters in flow drilling. Tool Nr. 1 (Fig. 3) with 5 mm diameter was used und two different thicknesses of the specimen with $t_{w1} = 4$ mm and $t_{w2} = 5$ mm were studied. A peripheral speed of $v_p = 80$ m/min and two feed rate of $v_{F1} = 100$ mm/min and $v_{F2} = 200$ m/min were applied. No lubricant was used during the experiment.

Table 1: Measured thrust forces and torque parameters

Tool diameter D in mm	Thickness t_w in mm	Peripheral-speed v_P in m/min	Feed rate v_f in mm/min
D = 5	$t_{w1} = 4$	$v_P = 80$	$v_{f1} = 100$
	$t_{w2} = 5$		$v_{f2} = 200$

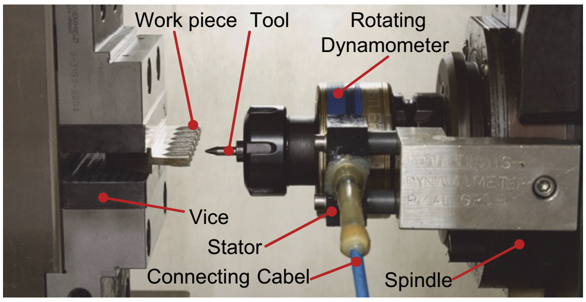


Fig. 4: Experimental setup - Flow drilling on AZ31

In flow drilling, temperatures near to the melting point of workpiece material can be achieved [3]. The temperature generated in this process may reach very high values that may further lead to fire hazards, hence in order to keep the process in check, continuous monitoring of temperature is required [4]. It is therefore important for a reliable process, to measure the temperature during flow drilling.

For determining process temperature during the process, an InfraTec infrared camera model ImageIR® 8300 was used. **Fig. 5** presents this experimental setup. The same machine as shown in Fig. 4 that is used to determine the force and the moment is employed for determining the temperature with experimental set up as shown in Fig. 5. To isolate the environmental influence, the transmission distance between the workpiece and the camera outside the machine was shielded. For attaining a high degree of transmission and to secure experimental set up, a sapphire glass was used. The temperatures outside of the bore wall were measured during the flow drilling. In order to get a high emissivity, the bore wall was coated with a black color. The measured temperatures were then evaluated digitally.

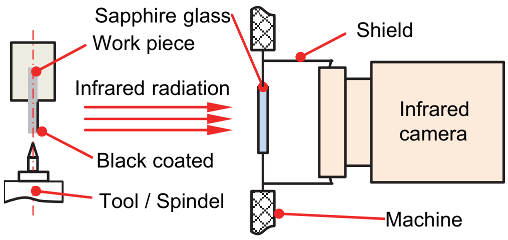


Fig. 5: Experimental setup - Measurements of temperatures

To find the influence of tool diameter on the thermo-mechanical loads, two flow drilling tools with different diameters of $D_1 = 5$ mm and $D_2 = 5.4$ mm were used. These experiments were performed with $v_p = 80$ m/min and $v_F = 100$ mm/min. The workpiece has a thickness of $t_w = 5$ mm. No lubricant was used in drilling.

After the temperature measurement during flow drilling, thread tapping and forming have been used to produce threads with size M6 ISO metric in the holes. Liquid lubrication has been used during the experimentation. The temperatures during threading were monitored with an infrared camera as well. To examine the thread profile, bore wall is removed by milling.

3. Analysis of experimental results

3.1. Thrust force and torque in flow drilling

Fig. 6 and Fig. 7 present the measured thrust force and torque during the experiment of flow drilling on the specimen with the thickness of $t_w = 4$ mm and $t_w = 5$ mm. For a better understanding, they are combined with the geometry of the used tool. The process is shown based on the time and all processes have similar shapes.

At the beginning of drilling, the center region of the tool enters the material. The thrust force and torque are low, because the contact area between the tool and material is also low. The frictional heating remains low as well.

With increased drill depth, the conical part of the tool is penetrated into the workpiece material. The contact area increases and as a result, more frictional heat is generated and the temperature in the contact zone continues to rise. The thrust force reaches its first maximum value and reduces again, before the conical region has completely entered in the work piece. The torque increases almost linearly. In this stage, the profile wall is expanded partly by the tool.

As the cylindrical region of the tool is engaged, the thrust force and torque remain at a constant level. It could be assumed, that a quasi-stable deformation zone is developed in the center and conical region. This deformation zone moves with the tool in the feed direction. The profile wall is continuously expanded by the tool and a closed bore is finally formed by the cylindrical part of the tool. In this case, the cylindrical part maintains the shape of the bore wall, and therefore it does not have much effect on friction. The deformation work is substantially done by the front part of the tool.

Just before the process is over and the required drill depth is attained, the thrust force has reached its second peak and the torque is at its maximum as well. This happens because of the shoulder of the tool, which is already marked in Fig. 3, pushes the back-extruded work material in and flattens it. For this reason, the torque at the end of the process is even larger than during the process.

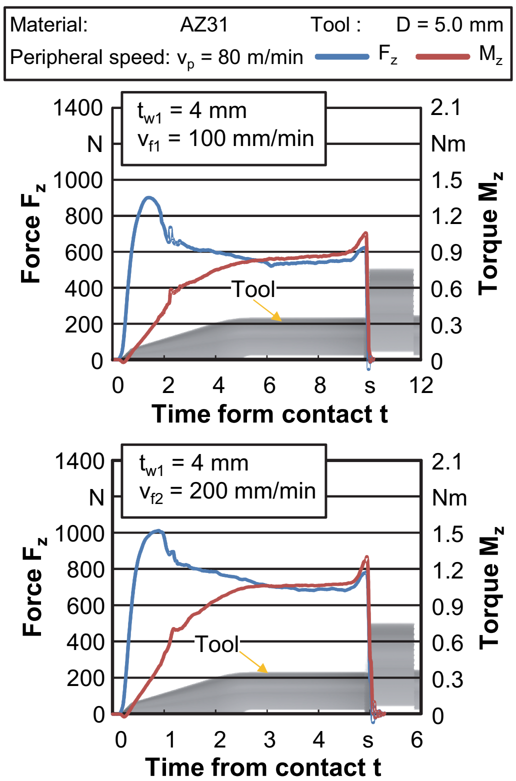


Fig. 6: Thrust force and torque in flow drilling on t_w = 4 mm in AZ31 profile

The influence of feed rate and wall thickness on flow drilling can also be seen from the measurement. Larger forces and moments occur mainly, when the feed rate is increased. It can be confirmed at the both thickness. An explanation of such is the high forming speed by high feed rate.

The influence of the wall thickness on thrust force in flow drilling is complicated in comparison to the feed rate. At a low feed rate of v_{f1} = 100 mm/min, the measured thrust forces of drilling at t_{w1} = 4 mm and t_{w2} = 5 mm AZ31 show similar trend. Only at higher feed rate of v_{f2} = 200 mm/min, the two curves can be distinguished from each other and the trend shows a falling thrust force with increasing wall thickness. The torque always increases with increasing wall thickness, because more work is needed for the forming and the most of the forming work is done by torque **[6]**.

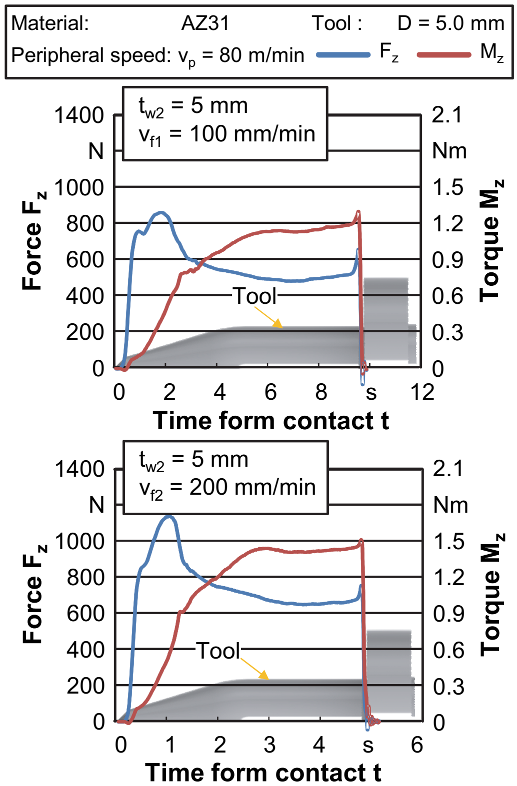


Fig. 7: Thrust force and torque in flow drilling on t_w = 5 mm in AZ31 profile

3.2. *Temperatures in flow drilling*

Fig. 8 shows temperature measurement results, in which the temperature field of the surface outside of the bore wall can be identified. It shows the temperature field by reaching the drilling depth. The shapes of the tool are shown with the same scale, as they reach the drilling depth.

Higher temperatures may occur inside the workpiece and tool interface regions during the flow drilling process. The bore wall around the tool has temperatures over 350 °C. Because of the distance between the surface of bore wall and the tool, the temperatures between workpiece material and tool must be even higher than at the surface. In theory, magnesium wrought alloy can be formed from T = 225 °C **[7]** and these temperatures are surpassed in flow drilling.

The highest temperatures can be detected at the area where the conical region of the tool is in the bore wall. For this reason, it can be assumed that the conical part of the tool makes the most of the deformation work. In this region, where the tool tip and cylindrical part of the tool are located, the temperatures are lower. At the tool tip, the contact between tool and the work material is always small, as compared to the conical region of the tool, hence lower frictional heat is generated. The cylindrical region of the tool, maintains the formed bore wall during the process and for this reason, there is low friction in this area as well, resulting in not so high temperatures.

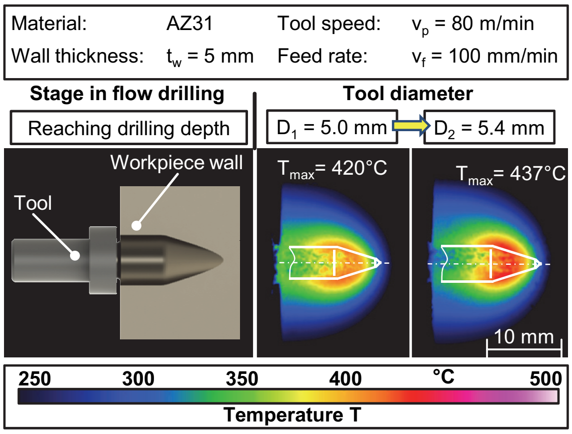


Fig. 8: Temperature field in flow drilling and influence of the tool diameter

Enlarging the tool diameter leads to a higher temperature during the process. With the D_1 = 5 mm tool, a maximum temperature, T_{max} = 420 °C was recorded. Under the same peripheral speed and feed rate, a higher maximal temperature, T_{max} = 437 °C was registered. The reason is that more material must be formed with larger tool in flow drilling which means more work needs to be done for the forming operation.

3.3. Tapping and thread forming

With this new application of flow drilling, usable blind holes can be made on thin-walled profiles consisting of AZ31. An internal thread can be machined in this hole and its depth is significantly greater than the local material thickness.

In this article, in addition to tapping, the possibility of the thread forming was examined. **Fig. 9** shows the threads produced by tapping and thread forming after flow drilling at a t_w = 4 mm specimen. Threads with closed bore wall can be machined. M6 ISO metric threads with a thread depth of L = 10 mm can be machined at magnesium profiles. The ratio thread size to the wall thickness t_w is 1.5 and the ratio thread depth L to wall thickness t_w is even 2.

Sectional views of the machined threads produced by tapping and thread forming processes are shown in **Fig.** 10. Tapping is a machining process to generate internal threads, by tapping a better thread profile can be generated, hence, tapping is used for generating threads after the flow-drilling process (Fig. 10, Tapping). Thread forming is a chipless process and it requires the material to be machined must have sufficient ductility. Cross section of formed thread shows that the thread profile is not optimally formed (Fig. 10, Thread forming). In longitudinal direction, the thread form shows that there is no space pocket (Fig. 10, Thread forming I), which is normally expected after thread forming **[8]**. This is a sign that the diameter at this area is less than required and this could lead to higher friction during forming.

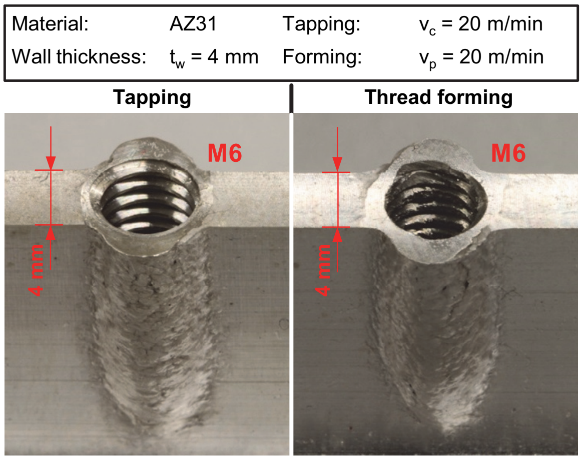


Fig. 9: Threads made with tapping and thread forming

The formed thread flank (Fig. 10, Thread forming II) shows micro fracture, which can be attributed to the insufficient formability of the magnesium alloy at low temperatures. Due to hexagonal closed-packed crystal structure, magnesium has slight ductility at low temperature **[9]**. In threading, low temperatures can be confirmed with the measured temperature field, which is represented in **Fig. 11**. With the same spindle speed, the temperature in thread forming (T_{max} = 55 °C) is higher than those (T_{max} = 40 °C) in tapping. Even though, the temperature is far lower than really needed for the forming of magnesium.

In order to solve this problem of magnesium alloy AZ31 having little ductility at room temperature, the work piece may be preheated or the forming tool can be preheated **[10]**, so that the optimum thread profiles can be achieved.

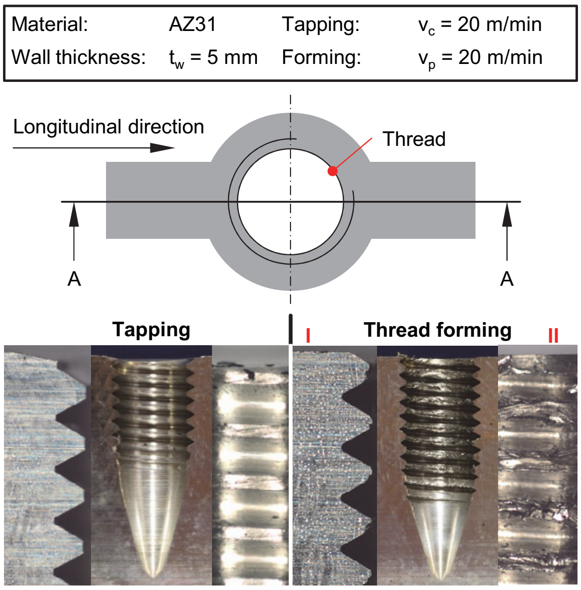


Fig. 10: Section view of threads made with tapping and forming in a flow-drilled hole

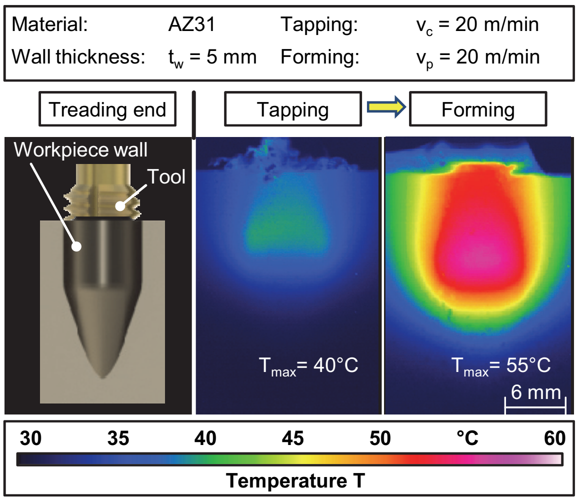


Fig. 11: Temperature field in tapping and thread forming

4. Conclusions

In this article, a new application of the flow drilling is investigated, in which blind holes can be machined on thin walled profiles of the magnesium wrought alloy AZ31. Thrust force and torque increase when feed rate increases. High temperatures occur during drilling process. An internal thread with greater size and depth than the local wall thickness can be manufactured through tapping. This application offers an unprecedented solution for the lightweight design with magnesium alloys. Flow drilling process is discussed here in detail. Further investigations include the variation of the peripheral speed during flow drilling on workpieces of different thicknesses and the analysis of the quality of holes manufactured. Their pull out strengths will be studied.

Acknowledgements

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References

[1] Bargel, H., J.; Schulze, G.: Werkstoffkunde, Springer Verlag, 11. Auflage, 2012
[2] Miller, S. F.; Shin, A. J.: Friction Drilling – A Chipless Hole-Making Process, Proceedings of the ASME International Conference on Manufacturing Science and Engineering, Ypsilanti, 8.-11. Oktober 2006, pp. 911-918
[3] Engbert, T.: Fließbohrbearbeitung und Innengewindefertigung an Leichtbaustrukturen, Dissertation, Technische Universität Dortmund, Vulkan Verlag, Essen, 2011
[4] Lehmann, A.: Metallbrände richtig löschen, Feuerwehr – Retten Löschen Bergen, HUSS-Verlagsgruppe Berlin München, Oktober 2010, pp. 54-55
[5] Flowdrill Fließlochformwerkzeuge GmbH: Flowdrill – Technisches Handbuch, 2002
[6] Kretschmer. G.: Fließlochformen von Blechdurchzügen Teil I, Blech Rohre Profile, 28 (1981) 8, pp. 331-333
[7] Dröder, K.G.: Untersuchungen zum Umformen von Feinblechen aus Magnesiumknetlegierungen, Dissertation, Universität Hannover, 1999
[8] Emuge-Franken: Handbuch der Gewindetechnik und Frästechnik, Anwendungen – Tipps – Tabellen, Hrsg.: Emuge-Franken, Publicis Corporate Publishing, Erlangen, 2004
[9] Lei, X.F.; Liu, T.M.; Chen, J.; Miao, B.; Zeng, W.: Microstructure and Mechanical Properties of Magnesium Alloy AZ31 Processed by Compound Channel Extrusion, Materials Transactions, Vol. 52, No. 6, Special Issue on Platform Science and Technology for Advanced Magnesium Alloys, V, The Japan Institute of Metals, 2011, pp. 1082-1087
[10] Vollmer, C.: Beitrag zu den Möglichkeiten der spanlosen Innengewindeherstellung in Magnesium-Legierungen, Fortschritt-Berichte VDI Reihe 2, Nr. 523, Düsseldorf, VDI Verlag 1999